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PILOT SURVEY OF THE CONDITION OF SUGAR PINE ON THE SEQUOIA AND SHASTA-TRINITY NATIONAL FORESTS

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ABSTRACT

A pilot survey of the condition of sugar pine on the Sequoia and Shasta-Trinity National Forests was conducted utilizing a modified version of the Region 5 Forest Inventory design. On the Sequoia National Forest, data were collected on a total of 270 sugar pines on 23 plots. Eleven percent of the trees (on 35% of the plots) were infected with white pine blister rust. On the Shasta-Trinity National Forests, data were collected on a total of 146 sugar pines on 16 plots. Three percent of the trees (on 25% of the plots) were infected with blister rust. Mortality on the Sequoia NF plots was 7% and on the Shasta-Trinity, 3%. The mortality was more likely to be caused by factors other that blister rust.

The average number of stems per acre of sugar pine on the sample plots were of a size distribution similar to that of healthy, reproducing, uneven-aged stands, despite the presence of blister rust and other damaging factors.

The data collected represent the condition of sugar pine only on a subsample of Forest Inventory plots containing sugar pine on the two forests. A larger data set will be required to extrapolate these findings to all forest inventory plots containing sugar pine on the two forests, to all sugar pine on the two forests, or to the population of sugar pine in California.

INTRODUCTION

Sugar pine (Pinus lambertiana Dougl.) is one of the most important species of the mixed-conifer ecosystem of California. It is the tallest and largest of all pines, second in volume only to giant sequoia (Kinloch and Scheuner 1990). Its range extends from the western slope of the Cascade Range in north central Oregon south into California through the northern mountains of the Coast Range to Lake and Sonoma counties and down the Sierras, to the Sierra San Pedro Matir in Baja California. Over 80% of the growing stock is in California, where it occurs most extensively in mixed-conifer stands of the western Sierra Nevada. While relatively free from most native diseases, the species is highly susceptible to the introduced disease white pine blister rust, caused by the fungus Cronartium ribicola Fisch.

White pine blister is known to occur throughout that part of the sugar pine range north of the Tehachapi Mountains. The disease has not yet been found in the Transverse or Peninsular Ranges of southern California (Kinloch and Scheuner 1990). Nearly 60 years after its introduction to the state from Oregon, blister rust continues to kill sugar pines in California. The disease is still being detected on sites previously thought to be disease free, an indication that the blister rust epidemic in the state has not yet stabilized.

White pine blister rust causes branch and bole cankers on sugar pines of all sizes. Infections on small trees are usually lethal, since the fungus grows rapidly enough to completely girdle such trees. Older trees typically are not killed by the fungus, but may succumb to multiple branch and bole cankers.

In January 1990 the California Department of Fish and Game was petitioned to list sugar pine as a threatened species, based primarily on the perception that the sugar pine species "is decreasing alarmingly, both in total numbers and vigor, as a result of white pine blister rust." Forest Pest Management biological evaluations conducted during the late 1970s and 1980s (Byler and Parmeter 1979, DeNitto 1987, Kliejunas 1982, Kliejunas 1984), but relevant to only a portion of the sugar pine range, were incorrectly cited in support of this statement. Scientists in California agree that the survival of sugar pine as a species is not currently threatened. However, our own studies are being used as evidence to the contrary. We have, in fact, conducted no comprehensive surveys of white pine blister rust since the early 1970s. No surveys have been done of the sugar pine resource, per se. Thus, we cannot adequately describe the current disease situation or assess the relative impact of other factors on the sugar pine resource. We also cannot accurately predict the future threat of blister rust to sugar pine or assess the relative importance of the loss of individual trees.

To remedy this situation, Forest Pest Management is proposing a long-term comprehensive survey of the condition of sugar pine within its geographical range in California (the "target population"). Two primary objectives were developed for the full-scale field survey:

1. To characterize the current condition of sugar pine in California, including the incidence and severity of white pine blister rust, and

2. To characterize changes over time in the condition of sugar pine in California, including those caused by white pine blister rust.

The first objective would be met if we could obtain data which would provide answers to the following four questions:

1. To what extent is sugar pine represented as a stand component in the target population?

2. What is the incidence of white pine blister rust on sugar pine in the target population?

3. What is the severity of white pine blister rust on infected sugar pine in the target population?

4. What is the overall health status of sugar pine in the target population?

The second objective would require obtaining or utilizing data collected at multiple points in time. This objective would be met by answering one additional question:

5. What long-term impact are white pine blister rust, other pests, injuries, abiotic diseases, and anthropogenic factors having on sugar pine in the target population?

Three approaches to meeting the survey objectives were considered. One involved initiating a comprehensive, long-term survey of the target population which would be flexible enough to answer both existing and potential future questions regarding sugar pine in California, and which would lend itself to partitioning the data base into subpopulations to answer specific questions (post-stratification). Because of current and projected future limitations in personnel and funding for such a large-scale project, this approach was not considered feasible.

A second approach was to utilize already existing survey plots. Region 5's Forest Inventory group conducts a continuous forest inventory of timbered land on the National Forests in California. Each National Forest is inventoried on approximately a 5-year cycle, and plot locations and data from previous inventories could be made available to us.

A third approach involved tying into the National Forest Health Monitoring effort, which initiated a pilot survey in California in 1992. Access to and data from these plots could also be made available to us. The strategy we chose to investigate initially utilized Region 5's Forest Inventory plots. (A summary of the pros and cons of the latter two options and our reasons for choosing the R-5 forest inventory are included in Appendix A.) A tentative survey design was developed by adapting the Forest Inventory design to meet our objectives, and a pilot survey was conducted. The objectives of the pilot study were:

1. To test the methodology and overall feasibility of the proposed survey design from a logistical standpoint, and

2. To acquire a small data set which would allow us to conduct test analyses to confirm that useful and valid conclusions could be drawn from the types of data collected.

Two national forests were chosen for the pilot survey, the Sequoia National Forest in the southern Sierra Nevada and the Shasta-Trinity National Forests in northwestern California. The most recent Sequoia NF inventory had been completed in 1990, and all inventoried trees were tagged with metal tags. The Shasta-Trinity NFs were inventoried in 1980, and in some cases inventoried trees were numbered with tree paint. These forests were chosen to represent ones on which the plots should be easy to relocate (Sequoia) and ones on which the plots might be very difficult to relocate (Shasta-Trinity). They also represented areas where white pine blister rust has been present for many decades (Shasta-Trinity) and areas where presence of the rust is a relatively recent occurrence (Sequoia).

The design and results of the pilot survey, conducted in 1992, are reported here.

SURVEY DESIGN

The Region 5 Forest Inventory Design

The Region 5 Forest Inventory (USDA-Forest Service Pacific Southwest Region FIA User's Guide, unpublished) is based upon timber strata (type, size class, and stand density). The parameter which drives the design is tree volume per acre. Non-productive and non-timbered strata are not included in the sample. The inventory design consists of a multistage variable probability sampling procedure. In the first step, quadrangle maps (quad sheets) are selected at random with probability proportional to the acreage of national forest land on each quad. Approximately one-quarter of the quads on each forest are selected. Next, stratum polygons are selected on each chosen quad using a probability proportional to the acreage of the stratum which occurs on the quad. Finally, plot locations are chosen by selecting random x and y coordinates within the chosen polygons. Two plots are usually selected per polygon.

The sampling unit used is a five-point cluster plot laid out in the shape of an "L" oriented north and east, with each sample point consisting of three nested plots, one of variable radius to measure sawtimber and poles and two of fixed radius to measure saplings and seedlings. Sample points are separated by 132 feet in the older inventories (including the Shasta-Trinity) and 100 feet in the more recent inventories (including the Sequoia). Data recorded include dwarf mistletoe rating and death/defect, in addition to basic mensurational data.

Adaptation of the R-5 Forest Inventory Design

Our originally proposed survey design included remeasurement of all mensurational variables measured in the original inventory (when warranted by the date of the last inventory) and the collection of additional detailed information on diseases, insect pests, and abiotic and anthropogenic damaging

agents present on all trees in the plots. On the Sequoia NF, it was felt that the mensurational data collected in 1988 and 1990 were current enough that mensurational data need not be recollected. On the Shasta-Trinity NFs the mensurational data were 12 years old. Remeasurement of the same sample trees would provide us with immediate trend data for some mensurational variables. It was therefore proposed to collect pest and damage information on all plots, but to remeasure mensurational variables only on the Shasta-Trinity NF.

A test of the proposed survey design (a pre-pilot) conducted early in the summer revealed that such a plan was not feasible, considering the objectives of the sugar pine survey. First, the mensurational data were quite time-consuming to collect in relation to the information gained from them; second, recording all pests and diseases present on all species took time which could otherwise have been devoted to collecting more detailed information on sugar pine; and third, the small numbers of sugar pines picked up on the variable radius Forest Inventory plots provided little data in relation to the time necessary to relocate the plots. An alternate plot design was therefore developed.

Rather than using the original five-point variable radius plot design, two fixed-radius nested plots were established around the center point of the original cluster plot. A 3/4-acre (102-ft-radius) plot was used to measure trees greater than 1" DBH, and a 1/4-acre (58.9-ft-radius) plot was used to measure seedlings (<1" DBH and greater than 1 foot in height). These plot sizes were chosen by calculating the area that would yield approximately 15 sample trees per plot, based upon trees per acre values for sugar pine calculated from the original inventory data. To reduce the amount of time necessary to collect data not directly related to the objectives, data would be collected on sugar pine only. Limited mensurational data would be collected as outlined in the following section.

There were 60 plots on the Sequoia NF and 36 on the Shasta-Trinity NF containing sugar pine. It became clear from our pre-pilot that, even with the revised amount of data to be collected, it would not be possible to resurvey all 96 plots in one field season with the personnel available. Thus, the plots containing sugar pine were subsampled by randomly selecting two plots from each sugar pine-containing stratum. When there were less than two plots in a given stratum, it was combined with another similar stratum and two plots selected from the pooled plots (Table 1). The remaining sugar pine plots in each stratum were randomly assigned consecutive numbers and used as alternates in case a sample plot could not be resurveyed due to fire, logging, change of land ownership since the original survey, or inaccessibility. Using this subsampling design, 24 plots on the Sequoia and 18 on the Shasta-Trinity were selected for the final sample. Aerial photographs and maps were used to screen these 42 plots for change of ownership, obvious inaccessibility, or other potential problems, and alternates selected if necessary.

Since the original R-5 Forest Inventory design was a variable probability multistage design, estimates from our subsamples of sugar pine plots need to be formed by the same estimation procedures. Unfortunately, those procedures are not currently computer programmed for our use. Therefore, summaries in this report are simple tabulations or averages treating all plot data equally.

FIELD PROCEDURES

The original Forest Inventory plot centers were relocated on the ground when possible. In some cases the marked trees in a given plot could be found but the center marker could not be located. In these cases a prism was used to estimate as accurately as possible where the center point had been and the center was reestablished at this point. In cases where neither the plot center nor marked trees could be found, a new plot was established at the point where it was felt the original plot should have been located. If no sugar pine of any size were present within a 102-foot radius of the center point, the sugar pine plot was established around point number one of the 5-point cluster plot (the point furthest north on the "L"). If even the vicinity of the plot could not be located with certainty, an alternate plot within the same stratum was substituted.

All sugar pine greater than 1 foot in height (seedlings, saplings, poles, and sawtimber) within a 58.9-ft radius and all additional sugar pines greater than 1" diameter at breast height (saplings, poles, and sawtimber) within a 102-ft radius were sampled. Azimuth and distance from the plot center and diameter at breast height were recorded for each tree.

Any damage which was affecting or had the potential in the next 10 years to affect the growth or survival of each tree was recorded, along with the location of the damage on the tree and the cause, if known.

Tree height, age, and total number of blister rust cankers were recorded for all trees greater than 10 years old but less than 35 feet tall. Percent crown affected by blister rust was estimated to the nearest 5 percent for all other trees. Cankers were categorized as either branch or bole cankers. The year of the wood on which cankers occurred was recorded for up to 10 cankers per plot. The number of stems of Ribes plants on each 1/4-acre plot was estimated.

Additional information recorded on the data sheets included Forest, plot number, crew members, travel time (vehicle and foot) to reach the plot, time spent on the plot itself, and directions to the plot in enough detail to allow relocation. Witness trees were used to document the location of the plot center. Witness trees were tagged, and directions to the plot from the witness tree written on the tag and on the data sheets.

RESULTS

Logistics of the Survey Design

Twenty-four plots on the Sequoia NF and 16 plots on the Shasta-Trinity NFs were sampled. Of these 42 plots, 32 were successfully sampled without the need for an alternate plot. Seven of the originally selected plots could not be sampled due to lack of necessary photos, inaccessibility, or change of stratum resulting from fire or cutting, but alternate plots were available and were substituted. One plot on the Shasta-Trinity NFs (plot #S67, stratum HX) was inaccessible due to a change in ownership, and no alternate was available; thus, neither plot in the combined stratum (HX + KPX) was sampled. One plot on the Sequoia NF (plot #5, Stratum R4G) had burned and been cut and no alternate

was available; individual tree data were collected for only one plot in the combined stratum (R3G + R4G).

It took 12 individuals working in two-person crews a total of 76 person-days (including travel time to and from official duty stations), or an average of about one plot per day per crew, to complete the survey. Two factors account primarily for the amount of time needed to complete the survey. First, many of the crew members are based in San Francisco or Sacramento, which necessitated a drive of up to 5 hours to reach the base locations--the Supervisor's Offices (SO) or a Ranger District office on the Sequoia and Shasta-Trinity NFs. In addition, a drive of two hours or more was often required to reach the vicinity of the plots from the SO or District Office.

The second factor resulting in a large expenditure of time was the difficulty often encountered in attempting to relocate the original Forest Inventory plots once in the vicinity of the plot. On the Sequoia NF we were successful in relocating original plot center markers for 12 (52%) of the plots, marked trees but no center marker for 3 (13%) of the plots, and neither for 8 (35%) of the plots. On the Shasta-Trinity National Forest we relocated original plot center markers for 6 (37.5%) of the plots, marked trees but no center marker for 4 (25%) of the plots, and neither for 6 (37.5%) of the plots. Overall, then, we were unable to find and had to reestablish 14 (36%) of the 39 plot centers we attempted to relocate.

Our lack of success in relocating these 14 plots was due to a number of factors. Although the inventory plots were considered to be relocatable (but not permanent), in many cases there were no written instructions accompanying the original data sheets. Only in a few instances was a route to the plot marked with flagging, and in many cases on the Shasta-Trinity NF the inventoried trees were not marked. Many of the original aerial photographs showing pin-pricked locations of the plots were missing. When the photos were available, occasionally the location shown by pin-prick on a photo did not coincide with the location of the pin-prick on the photo pair, the location plotted on the quad sheet, or the location of the plot found in the field. Photos for the Shasta-Trinity were 17 years old and on the Sequoia 5-10 years old. More recent resource and ortho photos were not always available. When a plot could not be located despite our best efforts to find on the ground the spot indicated on the photo and map, it was not known if we were in the wrong location or if the plot had originally been installed in the wrong location.

Data were collected on a total of 270 sugar pines on the Sequoia NF and 146 on the Shasta-Trinity NF. The fixed radius plot sizes chosen did not provide as many trees as anticipated. The average number of saplings, poles, and sawtimber-sized sugar pines present on the 3/4-acre plots was 8.6, with a range from 1 to 34. The average number of seedlings present on the 1/4-acre subplots was 2.5, with a range from 0 to 23. An average of 1 hour was required to collect data once the plots were located or reestablished.

Data Collected

The number of stems per acre and the size distribution of sugar pines on the plots were measured as indicators of the extent to which sugar pine is represented as a stand component. An average of 21.4 live sugar pine stems per

acre were found on the survey plots on the Sequoia NF, and 18.4 on the Shasta-Trinity NFs. Live sugar pines of all diameter classes were present on the plots (Figure 1). On plots on both the Sequoia and Shasta-Trinity NFs, the greatest average number of trees per acre fell into the seedling size class, with the number of trees decreasing for the most part as size increased. This is the "inverse-J" relationship typical of healthy, reproducing uneven-aged stands. Across all size classes, the number of sugar pine stems per acre was greater on the Sequoia than on the Shasta-Trinity NFs.

The presence of blister rust cankers was recorded as an indicator of the incidence of white pine blister rust. On the Sequoia NF, 240 trees (89% of the total) were free of blister rust. Thirty trees (11% of the total) were infected with the rust, on 8 (35%) of the plots. These 30 trees represented all size classes except for the 15-20.9" class (Figure 2). On the Shasta-Trinity NFs, 141 trees (97% of the total) were free of blister rust. Five trees (3% of the total) were infected with the rust, on 4 (25%) of the plots. These 5 trees were in the seedling and pole (5-10.9" DBH) size classes (Figure 3).

The location of cankers (branch vs. bole) was recorded as one indicator of the severity of white pine blister rust. On the Sequoia NF, half of the infected trees had branch cankers only, while half had at least one bole canker. Bole cankers were present on trees in the seedling through 14.9" size classes. On the Shasta-Trinity NFs, one of the infected trees had branch cankers only, while the remaining four had at least one bole canker. The bole cankers occurred on both size classes of infected trees.

As another indicator of rust severity, tree age, tree height, and total number of cankers per tree for trees older than 10 years and less than 35 feet in height were used to calculate a "rust index." The rust index was developed for western white pine in the Intermountain Region (Hagle et al. 1989, McDonald et al. 1981) as an indicator of stand rust hazard. The index represents the number of cankers per 1000 needles per year, and takes into account the amount of time that susceptible tissue has been available for infection. Although it was developed as an indicator of rust hazard, it is used here as a quantitative measure of the amount of rust on individual trees. On the Sequoia NF, average rust indices on plots where rust was present ranged from 0.00018 to 0.02779. On the Shasta-Trinity NFs, average rust indices on plots with blister rust ranged from 0.00003 to 0.2222 (Table 2).

As an indicator of rust severity on trees for which rust index would not be calculated (those less than 10 years old or greater than 35 feet in height), the percent of crown affected by the rust was estimated. No blister rust was found on trees younger than 10 years. Blister rust was found on 8 trees on the Sequoia NF and 1 tree on the Shasta-Trinity NFs greater than 35 feet tall. Three of these trees were estimated to have less than 5% of the crown affected, 3 trees less than 10%, 1 tree 15%, and 1 tree 50%. (Percent crown affected was not recorded for one of the trees.)

Presence of damaging agents, mortality, and cause of death (if known) were recorded as an indicator of the overall health of sugar pine. Other damaging agents recorded on the Sequoia NF included fire (1 tree) and mechanical damage (4 trees). Other damaging agents recorded on the Shasta-Trinity NFs included

fire (3 trees), mechanical damage (5 trees), dwarf mistletoe (1 tree), and Atropellis canker (1 tree).

Of the 270 trees sampled on the Sequoia NF, 18 (6.6%) were dead. Eight of these (3% of the total) had died from blister rust while 10 (3.7% of the total) had died of other causes (Figure 4). Other identifiable causes of mortality included suppression and bark beetles. Of the 146 trees sampled on the Shasta-Trinity NFs, three (2.1%) were dead. One of these (0.7% of the total) had died from blister rust while 2 (1.4%) had died from other causes (Figure 5). Suppression was identified as the cause of death of one of these trees; the cause of death of the second could not be determined.

Two variables not directly related to our two primary objectives, age of canker wood and presence of Ribes, were also measured. These variables are related to rust epidemiology and were included on a trial basis to determine how much additional time and effort would be needed to obtain this information once on the plots.

To obtain information on infection years, the age of wood on which cankers were present for between one and eight cankers per plot containing blister rust was determined. A total of 29 cankers on the Sequoia NF and 8 on the Shasta-Trinity NF were aged. Years of wood on which infection was reported include 1981, 1982, 1984, 1986, 1988, and 1989 on the Sequoia NF and 1968, 1975-1977, 1981, 1983, 1984, and 1986-1988 on the Shasta-Trinity NF. (Some of the older dates represent bole cankers.)

As an indication of the relationship between blister rust on the plots and presence of the Ribes, the alternate host necessary for the fungus to complete its life cycle, the number of stems of Ribes present on the plots was collected. Ribes were present on 9 plots on the Sequoia NF. The sugar pine on 5 of these plots were free of blister rust infection; 4 of the plots had sugar pine infected with blister rust. Ribes were present on 2 plots on the Shasta-Trinity NF, both of which also had sugar pine infected with blister rust.

DISCUSSION

Logistics

The first objective of the pilot survey was to test the methodology and overall feasibility of the proposed survey design. Completion of the pilot survey did provide us with sufficient experience and data upon which to assess the methodology and judge the feasibility of the survey design for full scale implementation.

We found that the appropriate maps and aerial photographs were not as readily available as had been thought. We were unable to relocate the exact plot center in over one-third of our attempts. Thus, it seems that a decision to install new plots on the old plot centers rather than resurvey the exact trees of the original plot would have been forced on us, had we not made that decision earlier for other reasons. The designation of alternate plots was quite helpful, as an alternate plot was needed in nearly one-quarter of the cases. (Because the number of plots with sugar pine in each stratum varied,

alternate plots were not available to us in three cases when they were needed.) Had we desired to resurvey all sugar pine-containing inventory plots, as might be done in a full-scale survey, our success rate would have dropped further.

Much time was spent in travel from official work stations to local base stations. In the future it would be desirable to have crews stationed on the forest which is being surveyed. It would also be desirable to have a smaller number of crews each working for a longer block of time, so that the data collected would be more consistent and the crews could utilize the experience gained early on to expedite the survey process. There should be a training session with all crew members before the survey begins, so that all data are collected in as consistent a manner as possible.

Despite our attempts to include a greater number of trees on each plot by using a large fixed radius plot design, many plots had very few sugar pines. This could be remedied by increasing the size of the fixed radius plots, by including a greater number of subplots/plot in the survey, or both.

Limitations of the Data

Because the timber inventory survey design was not based upon the distribution of sugar pine in California, use of this design will not allow us to draw any statistically valid conclusions about that target population. We will therefore be able to fully meet our original objectives with this design only if we redefine our target population.

We could, theoretically, extrapolate our results to the sugar pine resource on the two forests surveyed, by stratum. To do this it is necessary to calculate the statistical weight each plot (and its associated data) represents, based upon the total number of plots with sugar pine available by stratum, and the expansion factors dictated by those weights. Each data point included in any analysis would then carry with it the appropriate expansion factor for the plot which the data point represents. (Expansion factors calculated for the plots surveyed in the pilot survey are shown in Appendix 2.) In addition, the sample of plots containing sugar pine was drawn by stratum, and each of the total plots from which the sample was drawn also has a separate associated expansion factor based on acreage by stratum, which would need to be applied to all data before proper analysis could be done. If the decision is made to proceed with a full scale survey of this design, it would be necessary to develop a computer program which would apply the appropriate expansion factors to each data point and incorporate them into all data analysis.

The data presented in this report, then, are estimates of the plots surveyed in the pilot survey, but not of all plots with sugar pine on each forest, all sugar pine on the forest, nor all sugar pine within its geographical range in California. Estimates calculated based upon the proper weights and expansion factors might yield very different results. Nonetheless, the pilot survey did provide information about the sugar pine on the 39 plots inventoried, and raised important questions which should be considered when designing the full-scale survey.

Analysis of the Data Collected

The second objective of the pilot survey was to acquire enough data to be able to conduct test analyses to determine if useful and valid conclusions could be drawn from the data collected. The data collected should ultimately help us address our overall survey objectives of characterizing the current condition of sugar pine including the incidence and severity of blister rust, and characterizing changes over time in that condition. The survey was designed to allow us to answer five questions relating to these objectives.

To what extent is sugar pine represented as a stand component within the target population? We collected data on number of sugar pine stems/acre by size class on the plots surveyed. On average, sugar pine is present in all age classes, in the inverse-J distribution typical of healthy, reproducing uneven-aged stands (Figure 1).

For those plots for which we were able to relocate the initial Forest Inventory plot and establish our fixed-radius plot on the same center point (15 plots on the Sequoia NF and 10 on Shasta-Trinity NFs), we can compare the stocking levels we found to those from the Forest Inventories completed in 1990 (Sequoia NF) and 1980 (Shasta-Trinity NFs). For most size classes, our survey estimated fewer stems per acre than did the Forest Inventory (Figures 6 and 7). These differences were statistically significant, however, only in the seedling, sapling, and 21-28.9" size classes on the Sequoia National Forest (Figure 6).

Even those differences between the two data sets which appear to be statistically significant may be due in part to the lack of weighting of the data from the sugar pine survey, and/or the difference in plot sampling designs and the clumpiness of sugar pine within stands. The Forest Inventory used a 1/100-acre plot to measure seedlings, whereas the sugar pine survey used a 1/4-acre plot. If sugar pine seedlings were distributed evenly, both methods would estimate a similar number of stems per acre for a given plot. If only one seedling were present near the center of the acre being sampled, however, the sugar pine survey would estimate 4 stems per acre while the Forest Inventory would estimate 100 stems per acre.

A similar explanation might account in part for differences in the larger size classes, where a variable radius plot was used in the Forest Inventory and a 3/4-acre fixed radius plot in the sugar pine survey. In the sapling size class on the Sequoia NF, for example, the Forest Inventory recorded sugar pine saplings on only 4 of the 15 plots, while the sugar pine survey found sugar pine saplings on 11 of the plots. Each of the 4 plots with sugar pine in the Forest Inventory had 2 sugar pine saplings, representing 40 trees per acre on each of these four plots and an average of 10.7 trees per acre for all plots. Each of the 11 plots in the sugar pine survey had between 1 and 11 saplings, but because of the plot type and size, these saplings represent an average of 3.9 stems per acre for all plots.

It is clear that a difference in plot design can greatly affect the reported estimate of the parameter sampled. The standard errors for the data collected in the sugar pine survey are typically much smaller than those for the Forest Inventory data (Figures 6 and 7), suggesting that a large fixed-radius plot may provide a more accurate measure of trees per acre for a clumped species such as sugar pine.

What is the incidence of white pine blister rust on sugar pine in the target population? The data collected allowed us to calculate the percentage of surveyed plots with blister rust present and the percentage of surveyed trees infected with blister rust. We found approximately four times as much blister rust on the Sequoia NF than we did on the Shasta-Trinity NFs, based upon percentage of surveyed trees infected (11% vs. 3%). Infected trees on the Sequoia NF were scattered throughout all but one size class, whereas infected trees on the Shasta-Trinity NFs were found only in the seedling and 5-10.9" size classes. The data we collected do not provide an explanation for these differences.

What is the severity of white pine blister rust on sugar pine in the target population? We used three methods in our attempt to answer this question. The presence or absence of bole cankers was recorded as an indication of lethal infections. All bole cankers found in the survey were on trees less than 14.9" DBH. Three-fourths were on trees less than 4.9" DBH, and would be expected to result in death of the tree. These results parallel those for tree mortality from blister rust (Figures 4 and 5), as would be expected.

A possibly more sensitive indicator of disease severity is rust index. In the Intermountain Region, stand rust index values are based on measurements of at least 100 western white pine per stand. Values less than 0.00005 are considered representative of very low hazard. Values greater than 1.0 are considered very high, with indices representing low, moderate, and high hazard falling in between (Hagle et al. 1989). In Oregon, rust indices between 0.0001 and 0.001 were found for sugar pine on low hazard sites, between 0.001 and 0.009 on moderate hazard sites, and greater than 0.009 on high hazard sites (Harvey Koester, personal communications).

Since we do not have a hazard rating system for white pine blister rust in California, we are using the rust index here as a quantitative measure of the amount of rust on individual trees in the plots rather than as a predictor of rust hazard. McDonald (personal communication) believes that the relationship of number of needles to crown volume developed by Buchanan (1963) for western white pine is appropriate for sugar pine, and that therefore it is appropriate to use the rust index for sugar pine without further modification.

Rust indices determined for those plots in our pilot survey which had blister rust (Table 2) indicate that the severity of blister rust varies considerably. We obtained values which would be considered indicative of very low, low, moderate, and high levels of rust hazard had they been calculated from data collected in the Intermountain Region. Both the lowest and the highest indices obtained in the pilot survey were from plots on the Shasta-Trinity NFs. With the small amount of data collected on blister rust in this survey it is difficult to group plots into severity categories; however, as more data are collected in the future, the rust index may be used to show, both tabularly and visually, different levels of blister rust severity across the state.

We also recorded percent crown infected by blister rust as an indicator of disease severity on trees for which rust index could not be calculated. This provided very little data, since no rust was found on trees younger than 10 years old and very little on trees greater than 35 feet. This may be useful in the future as more data are collected and could be pooled for analysis.

What is the overall health of sugar pine in the target population? We recorded the presence of agents which were impacting or might be expected in the next 10 years to impact growth or survival, mortality, and cause of death. On the Sequoia NF, white pine blister rust was recorded as a significant damaging agent 10 times as often as other causes. On the Shasta-Trinity NFs, other agents were noted twice as often as was blister rust. The presence of such damaging agents did not correlate, however, with tree mortality.

We found 7% mortality (3% due to blister rust) on survey plots on the Sequoia NF and 2% mortality (0.7% due to blister rust) on the Shasta-Trinity NFs. Estimated year of death was not recorded, so we cannot estimate an annual mortality rate. Trees were more likely to have been killed by factors such as suppression and bark beetles than by blister rust (Figures 4 and 5). In light of the healthy-appearing size class distribution of sugar pines on both Forests, it does not appear that an unacceptable amount of mortality is occurring on the survey plots; however, without additional data it is difficult to draw any clear conclusions. As data are collected from more forests, additional conclusions may be drawn.

What impact are white pine blister rust, other pests, injuries, abiotic diseases, and anthropogenic factors having on sugar pine in the target population? One of the initial reasons for deciding to use the Forest Inventory plots for the sugar pine survey was that some mensurational trend data would be immediately available to us. Because of our subsequent decision not to remeasure mensurational data on the plots, our ability to make comparisons at two points in time is limited. We did compare number of stems per acre by size class estimated by the forest inventories with that estimated in our study, for 25 common plots. Although some differences appeared, most are not statistically meaningful. On the Sequoia NF, statistical differences emerged in the seedling, sapling, and 21-28.9" size classes. The seedling and sapling classes on the Sequoia NF are also those for which the highest rates of mortality (most due to blister rust) were found in the current study (Figures 4 and 5). It is possible that recent mortality due to blister rust between 1990 and 1992 could account for the difference in number of stems per acre estimated for these two size classes in the two surveys. It is also possible that the differences are due to the different sampling designs and the small sample size involved (15 plots used in the comparison with Forest Inventory data, versus 23 total in the sugar pine survey), and/or the lack of weighting of the data obtained in the sugar pine survey. While the average numbers do not necessarily reflect what is occurring in individual stands, one might surmise from the healthy-appearing size distributions estimated from the full 23 plots on the Sequoia NF and 16 plots on the Shasta Trinity NFs (Figure 1) that the reproduction and survival of sugar pine on the plots surveyed are not being seriously impacted. Until additional plots throughout California are surveyed, and until the surveyed plots are revisited, little more can be said about the impact of white pine blister rust or other damaging agents on sugar pine in the target population.

Other parameters measured. The epidemiological variables measured included number of stems of Ribes present on the plots and year wood on which blister rust cankers occurred. There was confusion among crew members as to how to measure number of stems of Ribes, and inconsistencies between crews in this measurement, such that the validity of the quantitative data collected is

questionable. We did collect valid data on the presence or absence of Ribes on the survey plots, but were able to draw no correlations between this and the presence of white pine blister rust. Such a relationship may emerge as more data are collected. For the data to be more meaningful, however, it would be preferable to record the species of Ribes present as well, because of the different susceptibilities of the various species to infection by the rust fungus. This would be quite time-consuming, and a variable that we may want to eliminate when implementing the full-scale survey.

We found the the amount of data collected on year wood of blister rust cankers was inadequate to allow for analysis of the data. Because infection can occur on older as well as current tissue, the year wood on which a canker is present is not necessarily the year in which infection occurred. In order to estimate the primary infection years, data for a large number of cankers must be collected. The frequency of occurrence of cankers on a given year wood can then be used as an indication of the years in which infection most likely occurred. As with the amount of Ribes present, collection of such data would be time-consuming and not relevant to our primary objectives; thus, elimination of this from the full-scale survey should be considered.

Implications

The results of this pilot survey indicate that the objectives developed for the full survey cannot be met with the current survey design and available resources. Both the objectives and the survey design will be reevaluated and revised as necessary before proceeding with implementation of the state-wide survey.

Table 1. Timber Strata With Plots Containing Sugar Pine[a]

Sequoia NF			Shasta-Trinity NF		
Stratum	Total	With SP	Stratum	Total	With SP
M3G	13	7	D3G	6	2
M3P	21	3	D3P	6	3
M4G	15	6	D4G	6	2
M4P	18	4	HX	16	1[b]
R3G	10	1[c]	KPX	8	1[b]
R4G	12	1[c]	M2G	12	6
P4P	9	6	M2P	11	5
P3G	11	8	M3G	12	6
P3P	19	10	M3P+6G	18	8
J4G	10	1[d]	R3G	11	2
J4P	10	2[d]			
MG3--	6	5			
MG4--	6	4			
PLA	27	2			

[a]Key to Timber Types:
- D = Douglas-fir
- H = Hardwoods
- J = Jeffrey Pine
- KP = Knobcone Pine
- M = Mixed Conifer
- MG = Mixed Conifer with Giant Sequoia
- P = Ponderosa Pine
- R = Red Fir
- PLA = Plantation

Key to Size Classes:
- 2 = Poles
- 3 = Small Timber
- 4 = Medium Timber
- 6 = Two-Storied

Key to Stand Densities
- P = Light
- G = Heavy
- X = Not Determined
- -- = All Densities Combined

[b,c,d]Plots followed by similar letters were pooled prior to sub-sampling to provide at least two plots per stratum.

Table 2. Average Plot Rust Indices

Sequoia NF			Shasta-Trinity NF		
Plot	Stratum	Rust Index[a]	Plot	Stratum	Rust Index
110	J--	0	T29	D3G	0
247	J--	0	T46	D3G	0.2222
69	M3G	0	T27	D3P	0.00109
150	M3G	(0)[b]	T70	D3P	0
73	M3P	0.00018	T73	D4G	(0)
256	M3P	0	T74	D4G	0
49	M4G	0	T68	M2G	0
173	M4G	(0)	T18	M2G	(0)
52	M4P	0.02779	S17	M2P	0
54	M4P	0.00453	S18	M2P	0
167	MG3	0	T09	M3G	0.00003
188	MG3	0.02138	T50	M3G	0
169	MG4--	(0)	T19	M3P/6G	0
195	MG4--	--[c]	T65	M3P/6G	--[d]
94	P3G	.00035	S13	R3G	0
96	P3G	.00274	S14	R3G	0
163	P3P	0			
251	P3P	.00164			
82	P4P	0			
86	P4P	0			
26	R--	(0)			
302	PLA	(0)			
305	PLA	0			

[a]Number of cankers per 1000 needles per year. Although the rust index was developed as an indicator of rust hazard, it is used here as a quantitative measure of the amount of rust on individual trees.

[b]Rust index could not be calculated since there were no trees on these plots older than 10 years in age and less than 35 feet in height; however, there was no rust present on the plots.

[c]Blister rust was present on the plot but the data necessary to calculate rust index were not recorded.

[d]Blister rust was present in the upper crown of one tree on the plot, but total number of cankers could not accurately be counted, thus rust index could not be calculated.

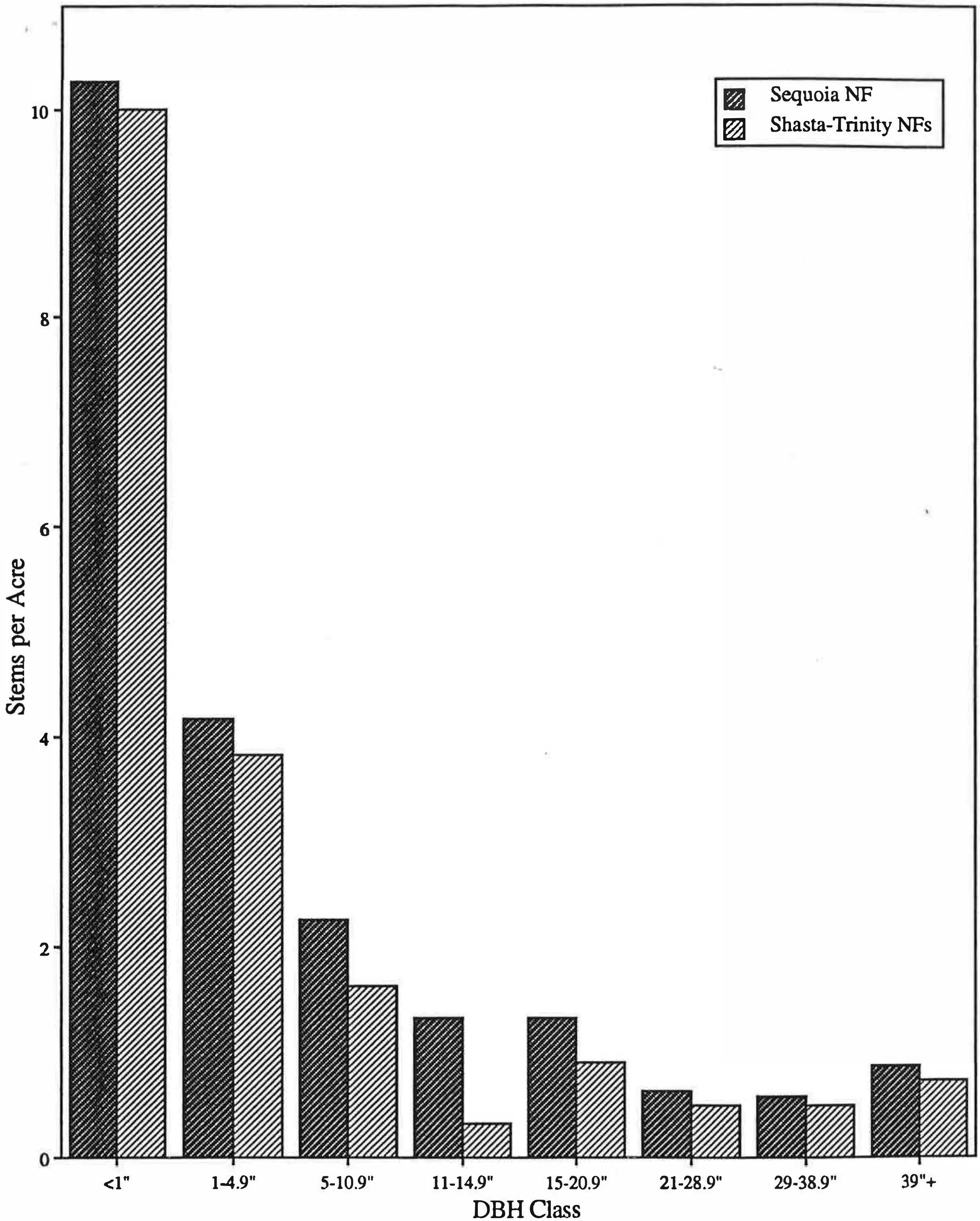

Figure 1. Average live sugar pine stems per acre on survey plots on the Sequoia and Shasta-Trinity National Forests, by DBH class.

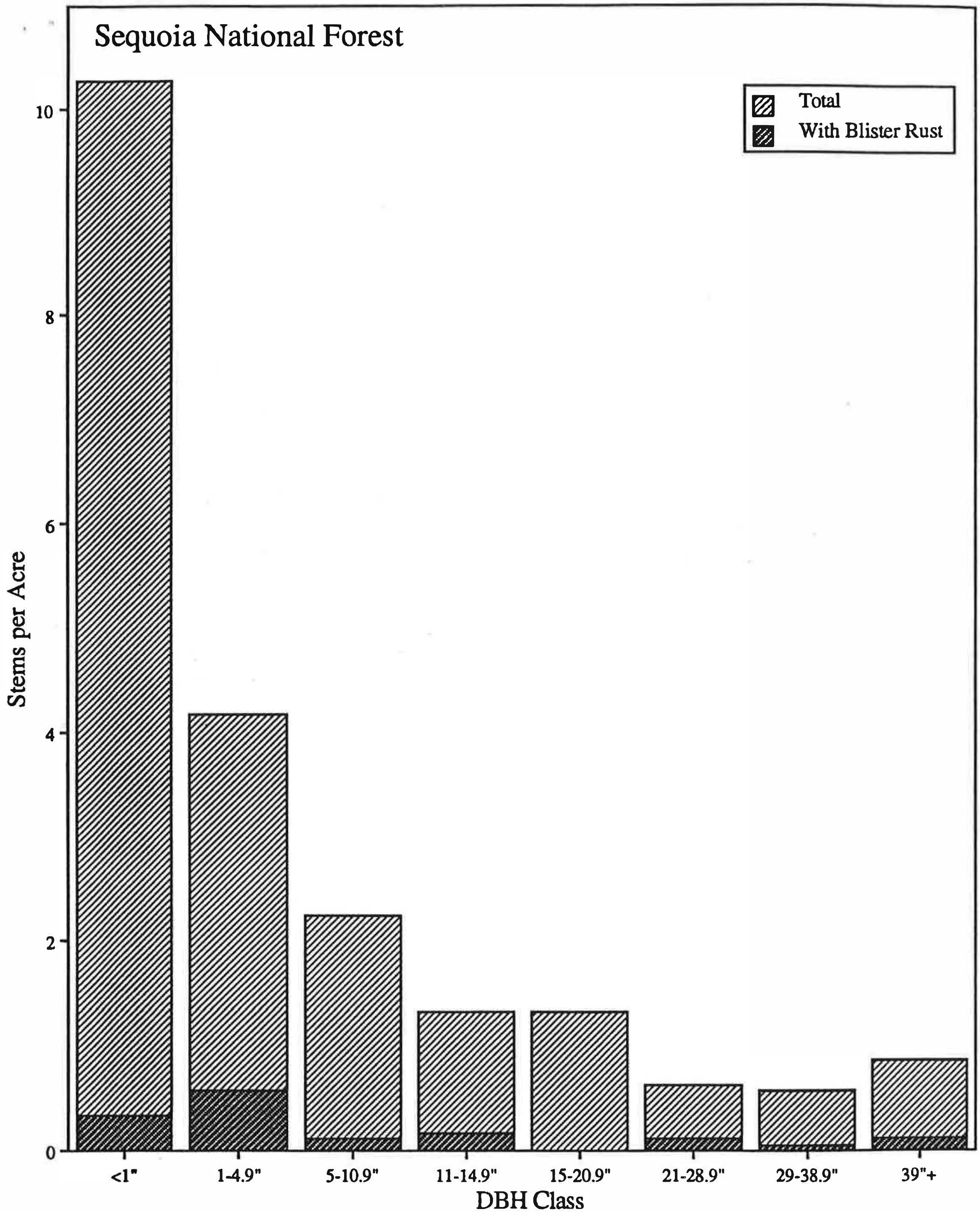

Figure 2. Average live sugar pine stems per acre and stems with white pine blister rust on survey plots on the Sequoia National Forest, by DBH class.

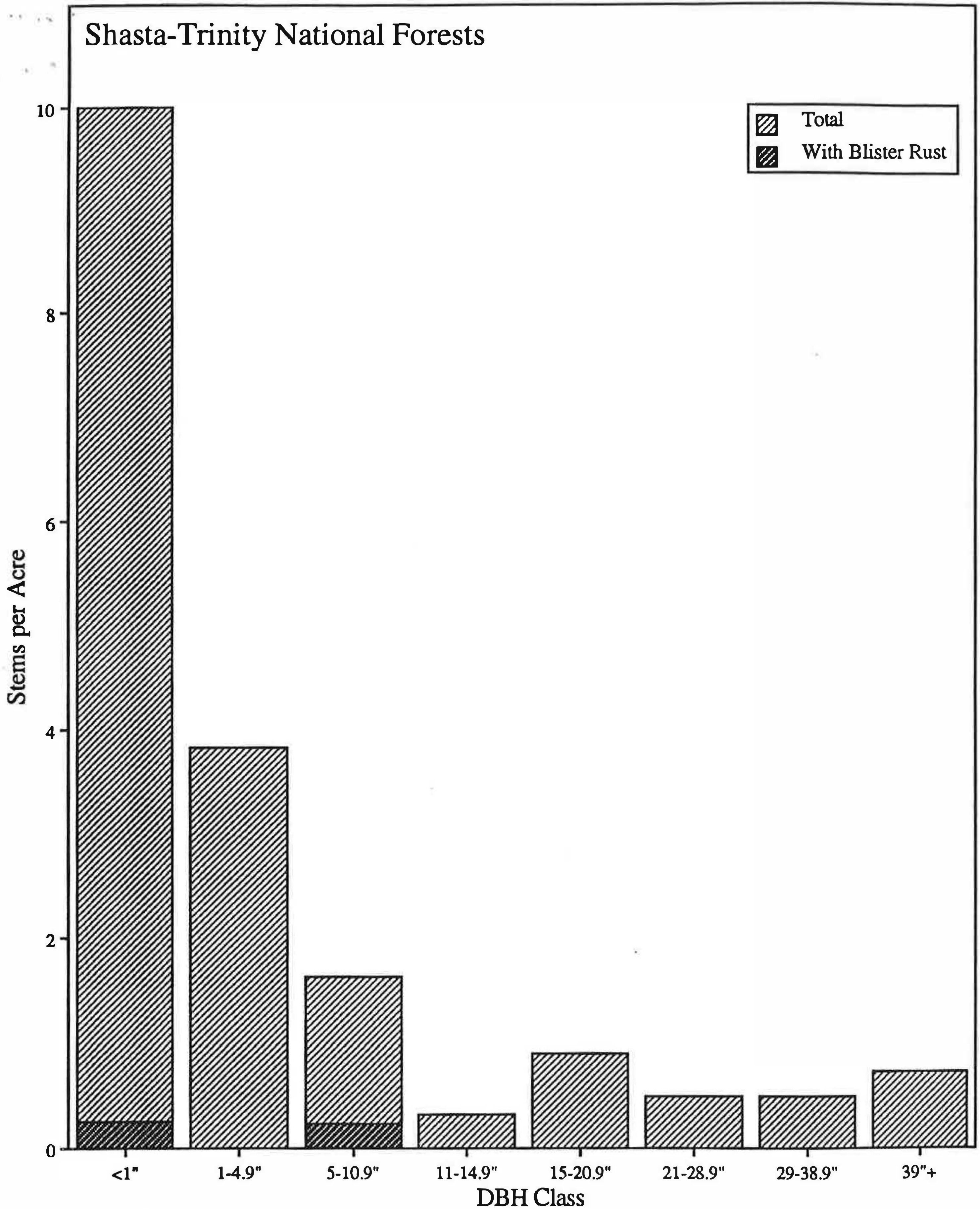

Figure 3. Average live sugar pine stems per acre and stems with white pine blister rust on survey plots on the Shasta-Trinity National Forests, by DBH class.

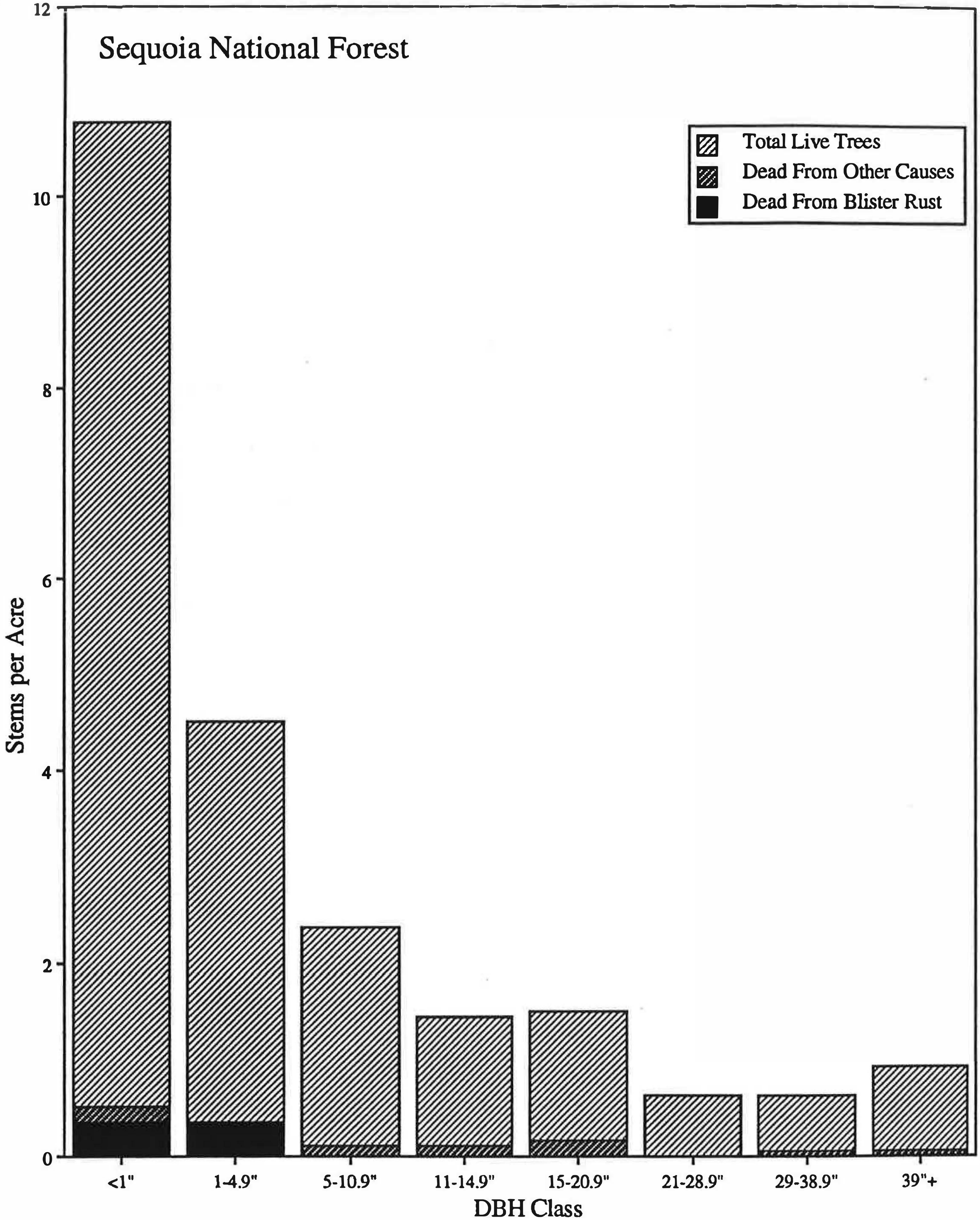

Figure 4. Average live sugar pine stems per acre, stems dead from blister rust, and stems dead from other causes on survey plots on the Sequoia National Forest, by DBH class.

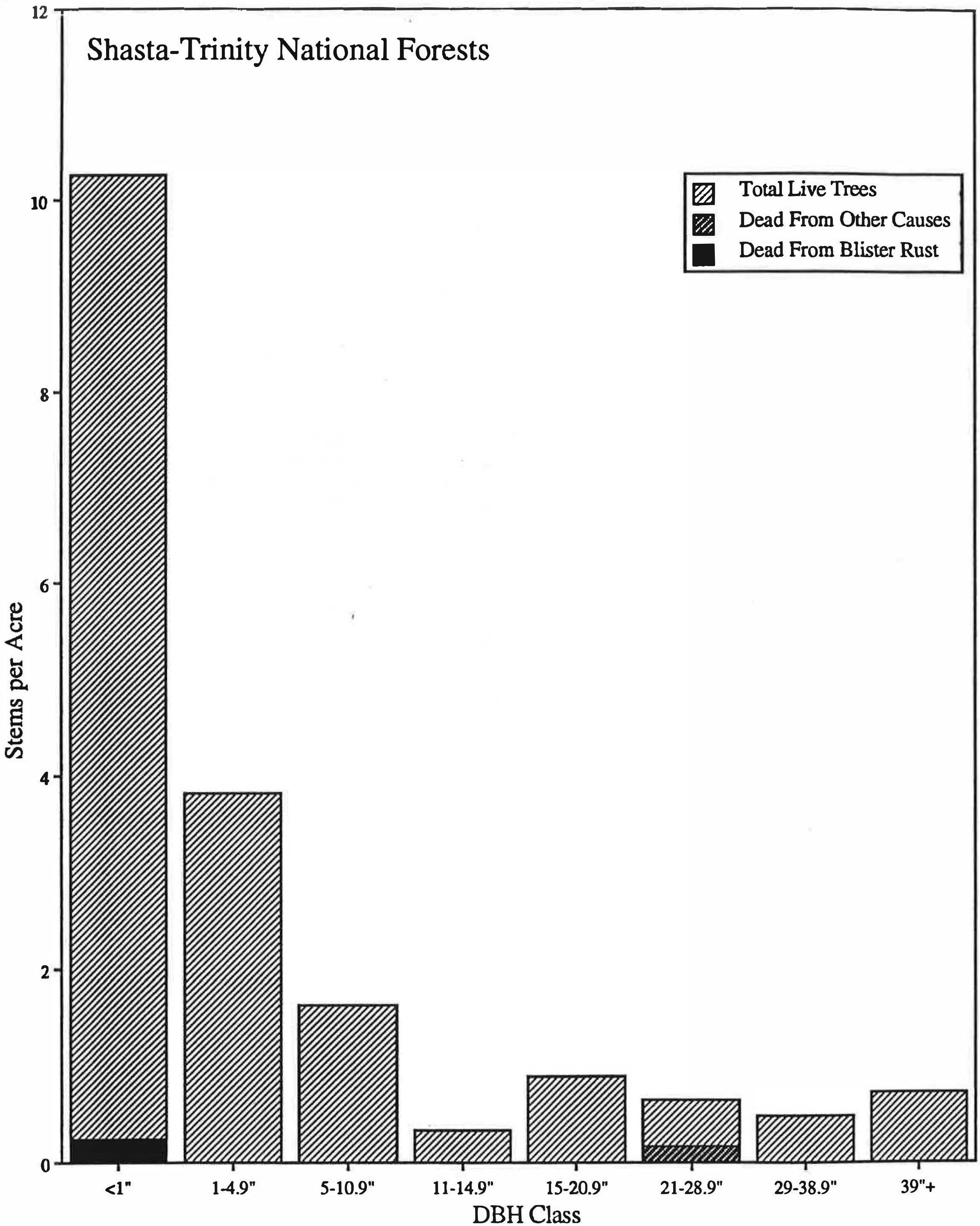

Figure 5. Average live sugar pine stems per acre, stems dead from blister rust, and stems dead from other causes on survey plots on the Shasta-Trinity National Forests, by DBH class.

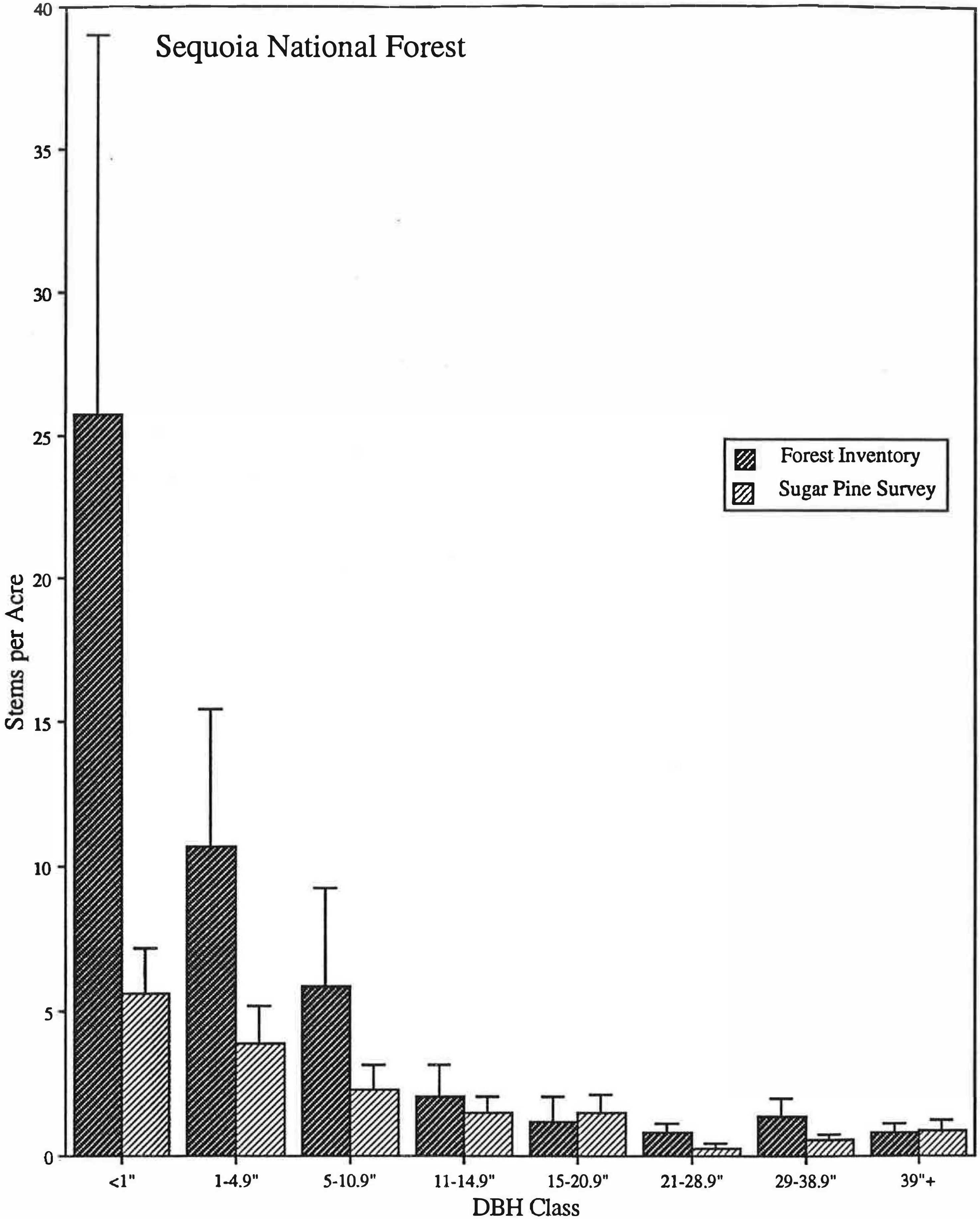

Figure 6. Average live sugar pine stems per acre on the Sequoia National Forest from 15 forest inventory and sugar pine survey plots, by DBH class. Bars represent standard errors.

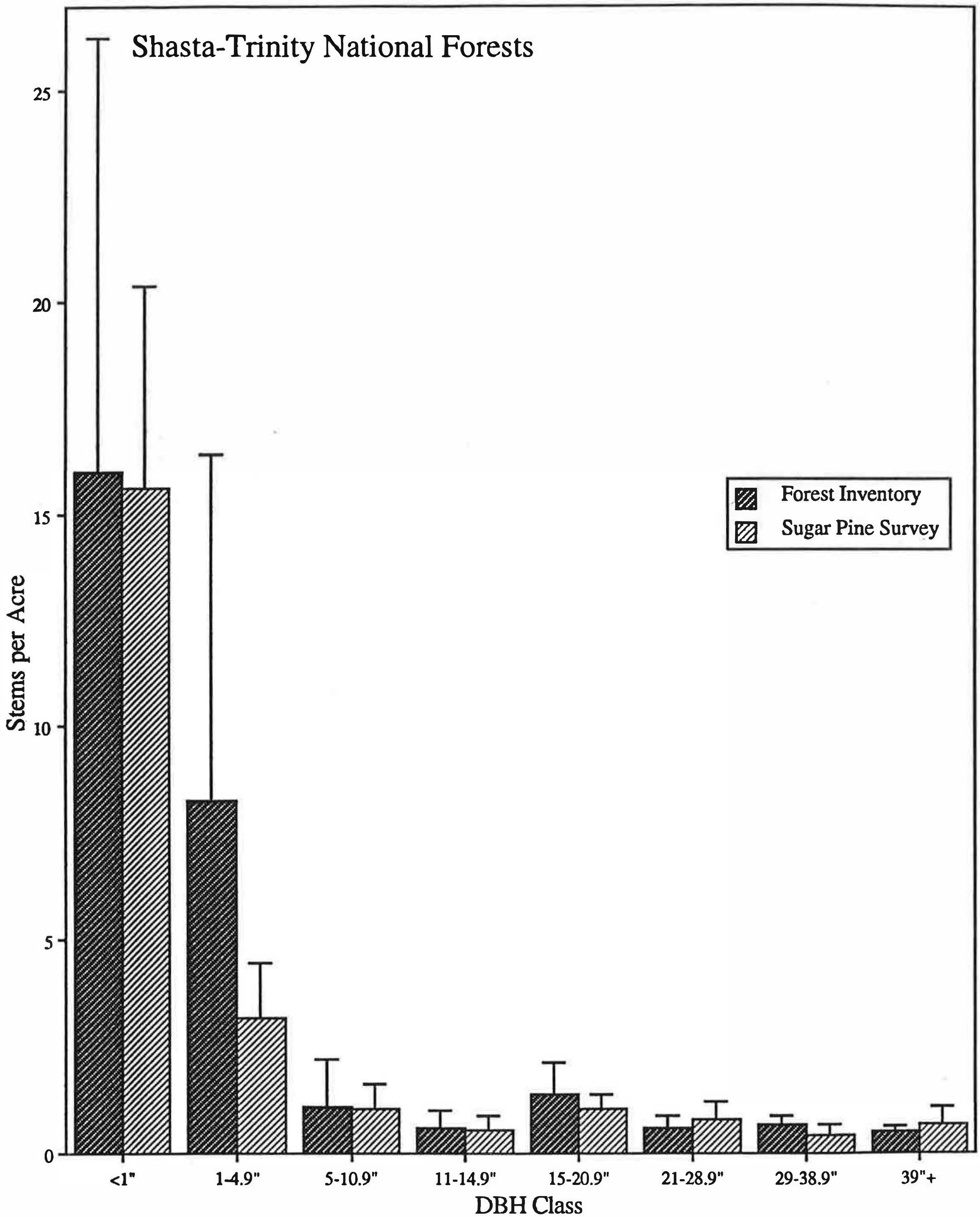

Figure 7. Average live sugar pine stems per acre on the Shasta-Trinity National Forests from 10 forest inventory and sugar pine survey plots, by DBH class. Bars represent standard errors.

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APPENDIX A

Analysis of Alternative Survey Designs

The Region 5 Forest Inventory and the National Forest Health Monitoring effort were considered as inventories upon which to base a survey of sugar pine in California. The feasibility of tying in with each of these efforts, and the advantages and disadvantages of each, were analyzed.

R-5 Forest Inventory

The incorporation of a sugar pine survey into Region 5's Forest Inventory would involve the remeasurement of existing plots. This approach offered a number of advantages. The plot design would provide complete (but not uniform) coverage of available Forest Service land. If the plots could be relocated, immediate access to mensurational trend data would be available. The cost of establishing the plots has already been incurred by the Region, and use of the plots would provide a link between the sugar pine study and the Region's Forest Inventory.

Along with these advantages, several disadvantages were identified. The Forest Inventory sampling design was based on timber strata, and is not related to the distribution of sugar pine or other subpopulations of interest in a survey of sugar pine. Thus, post-stratification would be difficult if not impossible to perform using the R-5 design. The design is based on a multistage, variable probability sample allocation, which provides very poor coverage of the sugar pine population (i.e. there are large unsurveyed areas). The variable radius plot design is not optimum for the evaluation of sugar pine on a given plot. In addition, non-Forest Service lands are not included in the inventory, nor are "non-suitable" lands within the National Forest boundaries (e.g. wilderness, roadless area) included. Thus, the design would have to be supplemented with additional plots both within and outside of National Forest boundaries.

The existing forest inventory plots range in age from 1 to 17 years; therefore, information is not current for any one point in time. This creates problems for estimating current status and trends. The plots are not permanent (but are considered by some to be relocatable). If an old plot could not be found, FPM would need to establish a new, more expensive plot as close as possible to the correct plot location.

Forest Health Monitoring

The incorporation of a sugar pine survey into the National Forest Health Monitoring (FHM) effort, which became operational in California in 1992, would provide the opportunity for a comprehensive long-term survey. As with the forest inventory approach, coordination with Forest Health Monitoring would have both advantages and disadvantages. The survey design offers uniform coverage of the state, with no large gaps. The equal probability systematic

sample design used is optimum when one is interested in many variables, as opposed to a single variable such as timber volume. Cooperation with FHM would provide full technical support in terms of planning, field operations, analyses, and reporting. The design would provide complete flexibility for enhancing the sampling intensity to meet the objectives of the sugar pine survey.

The incorporation of a sugar pine survey into the FHM effort would also present a number of disadvantages. The sugar pine survey might require a greater sampling intensity than that used by the FHM program; the cost of the additional plots would be the responsibility of R-5 FPM. The plots would have to be pre-screened for the presence of sugar pine, which could greatly increase the amount of time necessary to complete the survey. Mensurational trend data would not be available for four years, when the plots are scheduled for remeasurement.

The Selected Approach

The Region 5 Forest Inventory approach was chosen for full pilot testing in the summer of 1992. An overriding concern when weighing the pros and cons of each approach was current and projected future availability of funding and personnel to implement the strategy. With this in mind, our decision to use the Forest Inventory approach was driven by four factors.

First, using the Forest Inventory design, it would be known in advance which plots contained sugar pine. This knowledge would save considerable amounts of time, since the chosen plots would not have to be pre-screened for sugar pine.

Second, if the plots could be relocated, mensurational trend data would be immediately available for some forests (dependent upon the date of the original inventory).

Third, it was hoped that in the future, the sugar pine data could be collected by the Forest Inventory crews at the time of plot installation. The forest inventory plots currently existing would become the base for the sugar pine sample, would be made permanent, and would be revisited on a periodic basis. As new plots were installed through the forest inventory effort, those with sugar pine would be added to the base.

Finally, Region 5 expects to continue implementation of the Forest Inventory for the foreseeable future. It is not certain that annual funding for continuation of the Forest Health Monitoring effort will be forthcoming.

(Although we chose not to pursue use of the Forest Health Monitoring survey design for our sugar pine survey, Forest Health Monitoring crews did offer to collect a small amount of data on white pine blister rust as a part of their survey effort. An analysis of those data will be reported separately.)

APPENDIX B

Expansion Factors Calculated for Sugar Pine Survey Plots, by Stratum

Sequoia NF

Plot	Stratum	Exp. Factor
110	J--	3.22
247	J--	3.22
69	M3G	1.41
150	M3G	1.41
73	M3P	3.24
256	M3P	3.24
49	M4G	1.65
173	M4G	1.65
52	M4P	2.47
54	M4P	2.47
167	MG3	1.94
188	MG3	1.94
169	MG4--	2.47
195	MG4--	2.47
94	P3G	1.24
96	P3G	1.24
163	P3P	1.00
251	P3P	1.00
82	P4P	1.65
86	P4P	1.65
26	R--	4.88
302	PLA	4.88
305	PLA	4.88

Shasta-Trinity NF

Plot	Stratum	Exp. Factor
T29	D3G	3.95
T46	D3G	3.95
T27	D3P	2.64
T70	D3P	2.64
T73	D4G	3.95
T74	D4G	3.95
T68	M2G	1.32
T18	M2G	1.32
S17	M2P	0.16
S18	M2P	0.16
T09	M3G	1.32
T50	M3G	1.32
T19	M3P/6G	1.00
T65	M3P/6G	1.00
S13	R3G	3.95
S14	R3G	3.95

United States Department of Agriculture

Forest Service

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36,2362 -118,70304

Reply To: 3420 Evaluation

Date: JUL 0 7 1993

Subject: Pilot Survey of the Condition of Sugar Pine on the Sequoia and Shasta-Trinity National Forests (Rpt. No. R93-01)

To: Supervisors, Sequoia and Shasta-Trinity National Forests

The enclosed evaluation, "Pilot Survey of the Condition of Sugar Pine on the Sequoia and Shasta-Trinity National Forests," reports on the findings of the pilot survey conducted by Forest Pest Management during the fall of 1992. Implications for future sugar pine survey work throughout Region 5 are also included.

For further information or clarification of this evaluation, please contact Melissa Marosy (415) 705-2640 of our staff.

JOHN NEISESS, FPM Program Leader
State and Private Forestry

Enclosure